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(54) **METHOD AND APPARATUS OF MEASURING OBJECTS USING SELECTIVE IMAGING**

VERFAHREN UND VORRICHTUNG ZUR MESSUNG VON OBJEKTEN MITTELS SELEKTIVER BILDGEBUNG

PROCÉDÉ ET APPAREIL DE MESURE D'OBJETS UTILISANT UNE IMAGERIE SÉLECTIVE

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Description

PRIORITY

[0001] This patent application claims priority from United States patent application number 14/290,100, filed May 29, 2014, and from provisional application number 61/835,952, filed June 17, 2013, both of which are entitled, "**METHOD AND APPARATUS OF MEASURING OBJECTS USING SELECTIVE IMAGING**," and name Jonathan O'Hare and Stephen Darrouzet as inventors.

FIELD OF THE INVENTION

[0002] The invention generally relates to metrology and, more particularly, the invention relates to metrology using imaging devices.

BACKGROUND OF THE INVENTION

[0003] Coordinate measuring machines (CMMs) are widely used for the geometric inspection and measurement of manufactured objects having a multitude of features. These features are often dispersed throughout the object at different locations and in different orientations. To improve industrial processes using CMMs, many such machines should quickly direct a measurement sensor toward relevant features in a manner that minimizes the measurement cycle time. This has been especially true of tactile probing systems where a single point stylus must make many moves to collect sufficient data about each feature of an object. In some applications, this tactile inspection method is too slow. The art has responded to this problem by developing more advanced probing systems, such as laser point or line scanners, which collect more data with a smaller range of motion.

[0004] Computed tomography inspection systems also have been used for inspection and measurement. Undesirably, such systems known to the inventors require the acquisition of an object's entire volume. Accordingly, industrial computed tomography systems scan the entire object volume through a complete rotation of 360 degrees with a plurality of either 2D x-ray projection images (cone beam/flat panel scanners) or 1D X-ray scan lines (helical/line scanners). Software later reconstructs these images into planar slices or complete volumes for analysis.

[0005] One problem with this scanning approach is that it often collects a high volume of information. This high volume of data then must be processed, which takes a long time (e.g., 30-45 minutes, which is unacceptably long for many industrial inspection systems), and takes up extra space for data storage. Use of the prior art computed tomography approach for geometric inspection therefore often is quite impractical.

SUMMARY OF THE INVENTION

[0006] The invention is defined in the appended claims.

[0007] In accordance with one embodiment of the invention, a method of measuring an object registers the object with a nominal model of the object, and determines at least one feature of the object to scan. Next, the method controls an X-ray scanning device to scan, by moving or orbiting a source / detector pair around the object along an arc, less than the entirety of the object along an efficient trajectory calculated as a function of registering the object with the nominal model, to produce visual data representing at least one scanned portion. The at least one scanned portion has the at least one feature, while the X-ray scanning device is controlled as a function of registering the object and model.

[0008] The method further volumetrically reconstructs the at least one scanned portion of the object from the visual data to produce a volumetric reconstruction. Next, the method measures the at least one feature from the reconstruction. Sometimes, the method may determine a plurality of features of the object to scan, and control the X-ray scanning device to scan, by moving or orbiting a source / detector pair around the object along an arc, less than the entirety of the object to produce visual data representing at least one scanned portion-where the at least one scanned portion includes the plurality of features. In a similar manner, the X-ray scanning device may be controlled to produce visual indicia representing a plurality of scanned portions. The at least one scanned portion comprises at least a portion of the at least one feature.

[0009] The object is loaded into a CT machine that contains the X-ray scanning device, and sometimes has a fixture that does not obstruct the X-ray scanning device. The fixture may be movable in a variety of manners, such as in a translational direction and in a rotational direction. Moreover, the model may include a 3D CAD model. Indeed, among other things, the feature may include an internal feature or an external feature of the object. The X-ray scanning device may have a source that moves less than 360 degrees around the object when scanning the object. Among other ways, the X-ray scanning device may scan a plurality of intersecting planes of the object.

[0010] In accordance with another embodiment of the invention, an apparatus for measuring an object has a registration module configured to register the object with a nominal model of the object, and a fixture for supporting the object. The apparatus also has a controller, operatively coupled with the registration module, configured to control an X-ray scanning device to scan, by moving or orbiting a source / detector pair around the object along an arc, less than the entirety of the object along an efficient trajectory calculated as a function of registering the object with the nominal model, to produce visual data representing at least one scanned portion. The at least one scanned portion includes at least one feature that is automatically determined within the object to scan by the

registration module, and the scanner is controlled as a function of the registration of the object and model.

[0011] The apparatus further comprises a reconstruction module configured to volumetrically reconstruct the scanned portion of the object and a measuring module configured to measure the at least one feature from the volumetric reconstruction.

[0012] Illustrative embodiments of the invention are implemented as a computer program product having a computer usable medium with computer readable program code thereon. The computer readable code may be read and utilized by a computer system in accordance with conventional processes.

[0013] Accordingly, prior art computed tomography inspection systems have been used mainly for non-destructive testing purposes so that their design requires the complete acquisition of an object's entire volume since the exact location of internal features may be unknown. In today's industrial computed tomography systems, the entire object volume is scanned through a complete rotation of 360 degrees with a plurality of either 2D x-ray projection images (cone beam/flat panel scanners) or 1D X-ray scan lines (helical/line scanners). These images are later reconstructed by software into planar slices or complete volumes for analysis. One problem with this approach, when considering geometric measurement, is that often too much unwanted information is collected. Since features being measured for geometric analysis usually have known nominal locations and orientations within the object being inspected, a complete acquisition that includes all the volume between those features is unnecessary. The current computed tomography inspection systems known to the inventors act blindly to collect all of the data contiguously through the object. The collection of this superfluous data bogs down processing time, takes up extra space for data storage, and makes the application for geometric inspection of larger objects using computed tomography highly impractical.

[0014] Thus, as noted, illustrative embodiments position an object within a computed tomography system to collect data only in the relevant regions where features of interest lie. This may be accomplished by selectively scanning cross-sectional plans that are orthogonal to those features of interest and at a minimum spacing between scan plans necessary to preserve geometry accuracy.

[0015] A nominal definition of the object or CAD model is used to fully automate the process of determining where the features of interest lie within the object to be measured -a CAD model contains all of the geometric information about the features of interest, such as their orientation and position within an object. This information is used to strategically plan the scanning trajectories and number of projections required to effectively measure all the features of interest within an object without acquiring superfluous data and slowing down the reconstruction process. The prerequisite to using the nominal definition

is that it is in-sync, i.e., registered with the object so that the position and orientations can be known. This may be accomplished by knowing only a few reference data points on the surface of the part relative to how it is being held in the positioning system's fixture. These reference points can be determined in advance by having measurements of the fixture data and stored for later reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Those skilled in the art should more fully appreciate advantages of various embodiments of the invention from the following "Description of Illustrative Embodiments," discussed with reference to the drawings summarized immediately below.

Figure 1 schematically shows an imaging system that may be configured in accordance of illustrative embodiments of the invention.

Figure 2A schematically shows top and perspective front views of an exemplary object that may be scanned in accordance with illustrative embodiments of the invention.

Figure 2B schematically shows front and side views of the object of Figure 2A.

Figure 3A schematically shows the object of Figures 2A and 2B within the imaging device and positioned on a fixture.

Figure 3B schematically shows the object of Figures 2A and 2B, but rotated for scanning along another axis.

Figure 4 schematically shows an apparatus for measuring selected portions of an object.

Figure 5 shows a process of measuring an object in accordance with illustrative of embodiments of invention.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0017] In illustrative embodiments, a metrology x-ray scanning device cooperates with a computer system to scan only relevant portions of a known object. To that end, the system registers the object with a model of that same object to provide system awareness of the object itself, and the feature(s) of interest. After completing the registration process, the system uses the model information to scan appropriate regions relevant to the feature(s) of interest. Details of illustrative embodiments are discussed below.

[0018] Figure 1 schematically shows a metrology imaging and measurement system 16 that can selectively image an object 10 in accordance with illustrative embodiments of the invention. As shown, the system 16 includes a computed tomography machine ("CT machine 18") coordinated and controlled by an accompanying computer system 20. The CT machine 18 is shown in a cut-away view to detail some of its interior components.

[0019] More specifically, like others in the art, the CT

machine 18 in this figure has a housing that both forms an internal chamber for containing various components, and acts as a shield to x-rays. The chamber of the CT machine 18 contains an x-ray source 22 that transmits x-rays (typically) in a generally coneshaped pattern (a/k/a "cone beam"), toward and through an object 10 within its interior region. This interior region, which contains the object 10 being imaged as it is receiving x-rays, is referred to herein as an "active region 24." As known by those skilled in the art, the object 10 attenuates the x-rays to some degree, changing the pattern of x-rays on the opposite side of the object 10. A detector 26 on the opposite side of the object 10 detects this pattern, producing a two-dimensional representation/image of the object 10.

[0020] To obtain a three-dimensional representation/image, however, the system 16 moves the position of the object 10 relative to the x-ray source 22 and detector 26. Some CT machines 18 rotate the x-ray source 22 and detector 26 (referred to as "source/detector pair 22/26") while leaving the object 10 stationary. Other CT machines 18, such as that shown in Figure 2, rotate the object 10 and source/detector pair 22/26. Of course, various embodiments may use these and other arrangements. In the latter case, the object 10 may be positioned/supported on a rotating device, such as the platter of a rotary table 28 or fixture. Among other ways, the rotary table 28 may be configured to precisely rotate the object 10 a predefined amount each time it generates a two-dimensional image (discussed below). For example, the CT machine 18 may take 500 to 2000 two-dimensional images of the object 10 on the table 28. These two-dimensional images, which typically are taken from slightly different perspectives, often are referred to in the art as "projections."

[0021] Some systems use linear detectors, while other embodiments may use flat panel detectors. Depending on the system type (e.g., linear or flat panel), projections may be in the form of line images (e.g., linear system) or plane images (e.g., flat panel system) ultimately used to reconstruct cross-sectional slices or volumes, respectively. In the present invention, a volumetric reconstruction is performed.

[0022] Conventional software techniques convert this plurality of two-dimensional images/projections into a detailed, comprehensive three-dimensional representation of the object 10. For example, the computer system 20, which has a display device 32, a CPU/memory/logic within a chassis 34 (i.e., a computer), input device 36 (e.g., a keyboard and/or mouse), and other conventional components, may execute these conventional software routines to generate a three-dimensional representation of the object 10. The computer system 20, however, also may execute other routines that improve scanning throughput.

[0023] More specifically, as noted above, the present invention does not scan the entire object 10. Instead, the system 16 scans only relevant portions of the object 10. Figures 2A and 2B schematically show an object 10 that

may be measured in accordance of illustrative embodiments. It should be noted that this object 10 is merely exemplary and not intended to limit the scope of various embodiments. Accordingly, illustrative embodiments apply to objects 10 having many different shapes, sizes, materials, etc.

[0024] In this example, the object 10 is a rectangular box having a boss 38 extending from a front face (i.e., an external feature of the object 10), and a through-hole 40 in extending through an upper portion of its width (i.e., an internal feature of the object 10). To illustrate this more clearly, Figure 2A schematically shows a front perspective view of the object 10 (on the right), and a top view of the object 10 (on the left). This top view explicitly shows the boss 38 extending from the front face, and the through-hole 40 extending across its body in phantom/dashed lines. Figure 2B shows the same object 10, with the left side showing a front view and the right side showing a side view.

[0025] The front view shows the boss 38 extending from the face and the through-hole 40 extending through the width in phantom/dashed lines. In a similar manner, the side view shows the opening to the through-hole 40, and the boss 38 extending from the front face. One thing of note is that the two features of interest, the boss 38 and the through-hole 40, diverge from one another and thus, do not have generally parallel longitudinal axes. It also should be noted that while the features of interests have longitudinal axes, some features of other objects may be irregularly shaped, without well-defined axes, and still be capable of analysis by various embodiments of invention.

[0026] Figure 3A schematically shows the object 10 of Figures 2A and 2B within the imaging device/ scanning machine 18 and oriented to scan the boss 38 feature of the object 10. In a corresponding manner, Figure 3B schematically shows the object 10 of Figures 2A and 2B, but rotated ninety degrees for scanning along another axis-to scan the through-hole 40 of the object 10.

[0027] More specifically, both figures show the object 10 on the rotary table 28 of Figure 1, and a source/detector pair 22/26 for scanning the object 10. The outer housing 21 and other features are omitted from these figures to view these components. The rotary table 28 has an axle 42 extending downwardly from its general center. Although not shown, the axle 42 terminates at a mechanism that rotates the entire rotary table 28 about an axis formed by the axle 42. Among other things, this mechanism may include a precise motor, such as a stepper motor, that is controlled by the computer for precise angular rotations. In these drawings, rotational angles are represented by the Greek letter " ϕ " (phi).

[0028] In addition to rotating, the rotary table 28 also may move translationally relative to the source/detector pair 22/26 within the scanning machine 18. For example, some embodiments translationally move the rotary table 28 without moving the source/detector pair 22/26. Other embodiments, however, translationally move the

source/detector pair 22/26 without translationally moving the rotary table 28. Yet other embodiments may translate both the rotary table 28 and the source/detector pair 22/26. In a manner similar to conventional techniques, this relative movement is used to scan along the longitudinal axis of the feature being imaged.

[0029] While remaining stationary relative to one another (i.e., the detector and source 22), the source/detector pair 22/26 moves or orbits the object 10 along an arc identified in the drawings by the angle identified by the Greek letter theta " θ ." Moreover, between scans, this arc may be rotated relative to its center by some angle to scan along other trajectories. For example, the arc may scan directly over the top of the object 10 during one set of scans, and then rotate ninety degrees relative to its center to scan over the sides (e.g., the front) during another set of scans.

[0030] As shown in Figure 3A, the angle phi ϕ is designated at 0 degrees to scan the boss 38 (i.e., feature "A"), while Figure 3B rotates the rotary table 28 ninety degrees to scan the through-hole 40 (i.e., feature "B"). More specifically, only a portion of the object 10 is scanned. Figure 3A illustrates this by scanning only the boss 38 and a small interior portion of the body of the object 10. Accordingly, this embodiment scans this entire feature of interest (i.e., the boss 38), and little else. Figure 3B similarly illustrates this by scanning the top and bottom portions of the through-hole 40 (e.g., the terminal portions of the through-hole 40), while not scanning the rest of the through-hole 40. Unlike the boss 38, however, the system 16 scans only a portion of the through-hole 40—not its entire length. Accordingly, this eliminates the need to acquire, process, and analyze a great deal of needless data, consequently reducing the time required to measure the object 10. These embodiments therefore should reduce measurement times to commercially reasonable standards.

[0031] A specially configured logic apparatus 44 performs some of the requisite steps (discussed below with regard to Figure 5) to measure the selected portions of the object 10. To that end, Figure 4 schematically shows a few portions of the logic apparatus 44 in accordance with illustrative embodiments of the invention. These portions cooperate with other parts of the overall system 16 to measure relevant portions of the object 10.

[0032] In particular, the logic apparatus 44 includes a plurality of modules or sub-systems that communicate by means of a conventional communication mechanism, such as a bus 46. Indeed, those skilled in the art can use other communication mechanisms, such as a wireless medium, direction connections, etc. and thus, a bus is discussed by example only. Accordingly, those skilled in the art may select any of a number of different mechanisms for operatively coupling the modules.

[0033] The modules cooperate to perform the desired functions discussed below, ultimately measure a feature or portion of the object 10. To that end, the logic apparatus 44 includes a registration module 48 configured to reg-

ister the object 10 with a nominal model of the object 10. As discussed below, among other things, the model may include a computer aided design (CAD) model or other relevant type of nominal model known in the art. As known by those in the art, a CAD model typically has all the geometric information about the features of interest, such as their orientation and relative positions within the object 10. It is this specific information that drives various embodiments.

[0034] The logic apparatus 44 also includes a reconstruction module 50 configured to volumetrically reconstruct scanned portions of the object 10 from visual data generated by the source 22 and detector 26, and a measuring module 52 configured to measure the feature/por-
tions of the object 10 from the reconstructed object portions. A controller 54 uses the information from the other modules to control the system 16 to scan an appropriate amount of the object 10. Using information and instructions from the other modules, the controller 54 directs the source 22 and detector 26 to obtain visual data of prescribed portions of the object 10.

[0035] As discussed in greater detail below, each module may be implemented by hardware, software, or a combination of hardware and software. For example, some or all of the modules may be implemented as integrated circuits on a printed circuit board, as software components executing on the computer system 20, or both.

[0036] Figure 5 shows a process of measuring selected portions of the object 10 of Figures 2A and 2B in accordance with illustrative embodiments of invention. This process preferably permits measurement of a plurality of like objects 10. For example, this process can be performed at the end of a production line to measure objects 10 (e.g., a specialized type of propeller) the production line is manufacturing. It should be noted that this process is a simplified version of what could be a much longer process. Accordingly, the process may entail additional steps that are not discussed in Figure 5. Moreover, some embodiments may perform various steps in a different order than that described. Those skilled in the art should be able to make appropriate changes to the order and number of steps in the process, and still meet the scope of various embodiments.

[0037] The process begins by configuring the system 16 to measure one or a plurality of like objects 10, such as that shown in Figures 2A and 2B. Specifically, the process begins at step 500, which loads the CAD model into the system 16. Accordingly, the CAD model of the object 10 is stored in some storage device associated with the system 16. This step also may receive an identification of the features of interest to measure (e.g., the boss 38 and through-hole 40 of the object 10) by referencing those features as they appear on the CAD model of the object 10. Among other ways, these features may be entered by a technician, or through some automated process.

[0038] The process thus continues to step 502, in which an operator loads the object 10 into an imaging

machine 18 (e.g., a fixture in the machine 18), such as the CT scanning machine 18 shown in Figure 1. More specifically, the operator precisely positions the object 10 on the rotary table 28 in a prescribed manner, effectively registering the object 10 with the rotary table 28. This enables the system 16 to readily associate various portions of the object 10 with the rotary table 28, which enables system identification of various parts of the object 10. In illustrative embodiments, the rotary table 28 does not block relevant portions of the object 10 being measured.

[0039] The process then continues to step 504, which performs a number of configuration and calibration steps that permits the system to repeatedly measure the same type of object 10 multiple times. To that end, using the registration module 48, the process registers the object 10 (via the fixture) with a model of the object 10. Specifically, unlike clinical use of a CT scanner, it is expected that the technician/ operator should know the nominal features of the object 10 through the CAD model. Using the object 10 of Figures 2A and 2B as an example, the operator and system 16 should have the knowledge that the object 10 has:

- 1) a rectangular shape,
- 2) the short boss 38 extending from its front face, and
- 3) the through-hole 40 extending through its width.

[0040] In fact, the operator and system 16 also should know the general dimensions of the object 10, the inner dimension of the through-hole 40, the diameter of the boss 38, as well as the general contours of the object surfaces (i.e., the planarity of its surfaces). Accordingly, using the registration information of the object 10 and the rotary table 28 (discussed below), the system 16 registers the object 10 with the CAD model. In other words, using the CAD model, the system 16 already has informational knowledge of the object 10 as it is positioned on the rotary table 28 (even if the object 10 is not yet loaded) and thus, uses the CAD model to identify nominal portions of the object 10.

[0041] This step continues by calculating efficient trajectories for the source/detector pair 22/26 to scan the object. In so doing, this step searches the nominal model for the features of interest, determines approximately where those features are located on the actual object 10, and then generates scanning trajectories to acquire visual indicia/data of the features of interest. In illustrative embodiments, step 504 loads the CAD model into a simulation program that calculates trajectories that will capture the features of interest while scanning a minimal amount of unnecessary portions of the object 10. In other words, this step calculates trajectories for minimizing the amount of data that is gathered and ultimately processed in later steps. Accordingly, this step should further reduce the time to process the object 10. After calculating the trajectories, this step loads the desired trajectories into the controller 54, which controls the movement of the

source/detector pair 22/26.

[0042] At this step, the process may begin processing many different objects 10 that nominally have the characteristics of the object in the CAD model. Stated another way, the process now may measure many objects 10 intended to have the features of the CAD model. Although only one scan is discussed in the subsequent steps, those skilled in the art should understand that various steps (discussed below) can be repeated multiple times after registration is completed.

[0043] It also should be reiterated that although a CAD model is described and discussed, those skilled in the art can use other types of nominal models. Accordingly, discussion of a CAD model is for illustrative purposes only and not intended to limit all embodiments.

[0044] The process continues to step 506, which scans the desired portions of the object 10 to produce visual indicia/data representing the object 10. Among other ways, the features to be scanned may be pre-programmed as noted above, or selected at the time of scanning using the CAD model. Accordingly, illustrative embodiments image/ scan less than the entirety of an object as a function of the registration of the object 10 with the model.

[0045] To those ends, with reference to Figures 3A and 3B, the system 16 serially scans part or all of the features of interest of the object 10. The complete object 10 is not scanned-- only one or more portions of the object 10 are scanned. In the example shown, the system 16 first scans the boss 38 as shown in Figure 3A (feature A), and then scans the through-hole 40 as shown in Figure 3B (feature B). To scan the boss 38, the rotary table 28 is rotated to an orientation that enables the source/detector pair 22/26 to scan a prescribed amount along the longitudinal axis of the boss 38. In this case, as shown in Figure 3A, the system 16 only scans a small portion of the object 10.

[0046] Continuing with step 506, the process then rotates the rotary table 28 ninety 90 degrees, and then scans a first prescribed portion of the through-hole 40 and stops scanning. This is shown in the lower picture of Figure 3B. While continuing along the longitudinal axis, the system 16 then begins scanning at a prescribed point near the end of the through-hole 40, and completes scanning just after the end of the object 10/through-hole 40.

[0047] It should be noted that the source/detector pair 22/26 does not necessarily complete a full orbit around the object 10. Some embodiments rotate less than 360 degrees around the object 10 since the entire 360 degrees of information may be unnecessary (in some uses). The operator and/or system 16 may determine an appropriate amount of rotation. Moreover, the source/detector pair 22/26 may make multiple scans that are either parallel to each other, or intersecting each other. This was suggested above when discussing how the source/detector pair 22/26 may rotate its arc between scans. It thus is not necessary that all scans be parallel.

[0048] After scanning the appropriate portion or portions of the object 10, the reconstruction module 50 re-

constructs the object 10 using conventional reconstruction processes known in the CT art (step 508). The system 16 may display the reconstructed object 10 on the display device 32, store it in memory, or both. The process concludes at step 510, in which the measuring module 52 measures the desired features of interest of the reconstructed object 10.

[0049] Accordingly, illustrative embodiments image or scan only portions of the object 10 that are necessary to obtain an accurate measure of the feature of interest, significantly reducing measurement times. This advance should enable a more facile, effective industrial inspection process.

[0050] Various embodiments of the invention may be implemented at least in part in any conventional computer programming language. For example, some embodiments may be implemented in a procedural programming language (e.g., "C"), or in an object oriented programming language (e.g., "C++"). Other embodiments of the invention may be implemented as preprogrammed hardware elements (e.g., application specific integrated circuits, FPGAs, and digital signal processors), or other related components.

[0051] The disclosed apparatus and methods (e.g., see the various flow charts described above) may be implemented at least in part as a computer program product for use with a computer system. Such implementation may include a series of computer instructions fixed either on a tangible medium, such as a computer readable medium (e.g., a diskette, CD-ROM, ROM, or fixed disk). The series of computer instructions can embody all or part of the functionality previously described herein with respect to the system.

[0052] Those skilled in the art should appreciate that such computer instructions can be written in a number of programming languages for use with many computer architectures or operating systems. Furthermore, such instructions may be stored in any memory device, such as semiconductor, magnetic, optical or other memory devices, and may be transmitted using any communications technology, such as optical, infrared, microwave, or other transmission technologies.

[0053] Among other ways, such a computer program product may be distributed as a removable medium with accompanying printed or electronic documentation (e.g., shrink wrapped software), preloaded with a computer system (e.g., on system ROM or fixed disk), or distributed from a server or other remote device over the network (e.g., the Internet or World Wide Web). Of course, some embodiments of the invention may be implemented as a combination of both software (e.g., a computer program product) and hardware. Still other embodiments of the invention are implemented as entirely hardware, or entirely software.

[0054] Although the above discussion discloses various exemplary embodiments of the invention, it should be apparent that those skilled in the art can make various modifications that will achieve some of the advantages

of the invention without departing from the true scope of the invention.

5 Claims

1. A method of measuring an object (10), the method comprising:

10 registering the object with a nominal model, in particular comprising a 3D CAD model, of the object, the object having a plurality of features; determining at least one feature (38, 40) of the object to scan;
15 calculating an efficient trajectory for an X-ray scanning device to scan the at least one feature of the object, calculating being a function of registering the object with the model;
controlling the X-ray scanning device to scan (506) by moving or orbiting a source/ detector pair (22, 26) around the object along an arc (θ), less than the entire object along the efficient trajectory to produce visual data representing at least one scanned portion, the at least one scanned portion including at least a portion of the at least one feature;
25 volumetrically reconstructing (508) the at least one scanned portion of the registered object from the visual data, reconstructing producing a volumetric reconstruction; and
measuring (510) the at least one feature from the volumetric reconstruction,
30 in particular comprising loading (502) the object into a CT machine (18) comprising the X-ray scanning device.

2. The method as defined by claim 1 wherein determining comprises determining a plurality of features (38, 40) of the object (10) to scan, controlling comprising controlling the X-ray scanning device to scan less than the entirety of the object to produce visual data representing at least one scanned portion, the at least one scanned portion including the plurality of features.

3. The method as defined by claim 2 wherein controlling comprises controlling the X-ray scanning device to produce visual indicia representing a plurality of scanned portions.

4. The method as defined by claim 1 wherein the feature includes an internal feature of the object (10).

5. The method as defined by claim 1 wherein the feature includes an external feature of the object (10).

6. The method as defined by claim 1 wherein the X-ray scanning device comprises a source (22) that moves

less than 360 degrees around the object (10) when scanning the object.

7. The method as defined by claim 1 wherein the object (10) is positioned on a fixture (28) that does not obstruct the X-ray scanning device, in particular wherein the fixture is movable in both a translational direction and in a rotational direction. 5
8. The method as defined by claim 1 wherein controlling comprises controlling an X-ray scanning device to scan a plurality of planes of the object (10), at least two of the planes intersecting. 10
9. The method as defined by claim 1 wherein the x-ray scanning device comprises a flat panel detector. 15
10. An apparatus (44) for measuring an object (10), the apparatus comprising: 20
 - a registration module (48) configured to register the object with a nominal model of the object, in particular comprising a 3D CAD model, the object having a plurality of features (38, 40), to determine automatically where at least one feature of the object lies within the object to scan, and to calculate an efficient trajectory for an X-ray scanning device to scan the at least one feature of the object, calculating being a function of registering the object and the model; 25
 - a fixture (28) configured to support the object; 30
 - a controller (54) operatively coupled with the registration module, the controller being configured to control the X-ray scanning device to scan, by moving or orbiting a source/ detector pair (22, 26) around the object along an arc (θ), less than the entire object along the efficient trajectory to produce visual data representing at least one scanned portion, the at least one scanned portion including at least one feature; 35
 - a reconstruction module (50) operatively coupled with the controller, the reconstruction module being configured to volumetrically reconstruct the at least one scanned portion of the registered object from the visual data to produce a volumetric reconstruction; and 40
 - a measuring module (52) operatively coupled with the reconstruction module, the measuring module being configured to measure the at least one feature from the volumetric reconstruction, in particular comprising a housing (21) forming a chamber containing the fixture and the X-ray scanning device. 45
11. The apparatus (44) as defined by claim 10 wherein the fixture (28) is movable in both a translational direction and in a rotational direction. 50
11. The apparatus (44) as defined by claim 10 wherein the fixture (28) is movable in both a translational direction and in a rotational direction. 55

12. A computer program product for use on a computer system (20) for measuring an object (10), the computer program product comprising a tangible, non-transient computer usable medium having computer readable program code thereon, the computer readable program code comprising:

program code for registering the object with a nominal model of the object, in particular comprising a 3D CAD model, the object having a plurality of features (38, 40);
program code for determining at least one feature of the object to scan;
program code for calculating an efficient trajectory for an X-ray scanning device to scan the at least one feature of the object, calculating being a function of registering the object with the model;
program code for controlling the X-ray scanning device to scan (506), by moving or orbiting a source/ detector pair (22, 26) around the object along an arc (θ), less than the entire object along the efficient trajectory to produce visual data representing at least one scanned portion, the at least one scanned portion including at least a portion of the at least one, in particular an internal and/or external, feature;
program code for volumetrically reconstructing (508) the at least one scanned portion of the registered object from the visual data, reconstructing producing a volumetric reconstruction; and
program code for measuring (510) the at least one feature from the volumetric reconstruction.

13. The computer program product as defined by claim 12 wherein the program code for determining comprises program code for determining a plurality of features (38, 40) of the object (10) to scan, the program code for controlling comprising program code for controlling the X-ray scanning device to scan (506) less than the entirety of the object to produce visual data representing at least one scanned portion, the at least one scanned portion including the plurality of features.
14. The computer program product as defined by claim 12 wherein program code for controlling comprises program code for controlling the X-ray scanning device to produce visual indicia representing a plurality of scanned portions.
15. The computer program product as defined by claim 12 further comprising program code for loading (500) the model of the object into a CT machine (18) comprising the X-ray scanning device.

Patentansprüche

1. Verfahren zur Messung eines Objekts (10), wobei das Verfahren Folgendes umfasst:

Registrieren des Objekts mit einem nominalen Modell, das insbesondere ein 3D-CAD-Modell umfasst, des Objekts, wobei das Objekt eine Vielzahl von Merkmalen aufweist;
Bestimmen von mindestens einem Merkmal (38, 40) des abzutastenden Objekts;
Berechnen einer effizienten Bewegungsbahn für eine Röntgen-Abtasteinrichtung zum Abtasten des mindestens einen Merkmals des Objekts, wobei es sich bei dem Berechnen um eine Funktion des Registrierens des Objekts mit dem Modell handelt;
Steuern der Röntgen-Abtastvorrichtung zum Abtasten (506), durch Bewegen oder Umkreisen eines Quellen-/Detektor-Paares (22, 26) um das Objekt entlang eines Bogens (θ), von weniger als dem gesamten Objekt entlang der effizienten Bewegungsbahn, um visuelle Daten zu erzeugen, die mindestens einen abgetasteten Abschnitt darstellen, wobei der mindestens eine abgetastete Abschnitt mindestens einen Abschnitt des mindestens einen Merkmals beinhaltet;
volumetrisches Rekonstruieren (508) des mindestens einen abgetasteten Abschnitts des registrierten Objekts anhand der visuellen Daten, wobei das Rekonstruieren zu einer volumetrischen Rekonstruktion führt; und
Messen (510) des mindestens einen Merkmals anhand der volumetrischen Rekonstruktion, was insbesondere das Laden (502) des Objekts in eine CT-Maschine (18) umfasst, die eine Röntgen-Abtasteinrichtung umfasst.

2. Verfahren nach Anspruch 1, wobei Bestimmen ein Bestimmen einer Vielzahl von Merkmalen (38, 40) des abzutastenden Objekts (10) umfasst, wobei Steuern ein Steuern der Röntgen-Abtasteinrichtung umfasst, um weniger als die Gesamtheit des Objekts abzutasten, um visuelle Daten zu erzeugen, die mindestens einen abgetasteten Abschnitt darstellen, wobei der mindestens eine abgetastete Abschnitt die Vielzahl von Merkmalen beinhaltet.

3. Verfahren nach Anspruch 2, wobei Steuern ein Steuern der Röntgen-Abtasteinrichtung umfasst, um visuelle Kennzeichen zu erzeugen, die eine Vielzahl von abgetasteten Abschnitten darstellen.

4. Verfahren nach Anspruch 1, wobei das Merkmal ein inneres Merkmal des Objekts (10) beinhaltet.

5. Verfahren nach Anspruch 1, wobei das Merkmal ein

äußeres Merkmal des Objekts (10) beinhaltet.

6. Verfahren nach Anspruch 1, wobei die Röntgen-Abtasteinrichtung eine Quelle (22) umfasst, die sich um weniger als 360 Grad um das Objekt (10) bewegt, wenn das Objekt abgetastet wird.

7. Verfahren nach Anspruch 1, wobei das Objekt (10) an einer Haltevorrichtung (28) positioniert ist, die die Röntgen-Abtasteinrichtung nicht behindert, wobei die Haltevorrichtung insbesondere sowohl in einer Translationsrichtung als auch in einer Drehrichtung beweglich ist.

8. Verfahren nach Anspruch 1, wobei Steuern ein Steuern einer Röntgen-Abtasteinrichtung umfasst, um eine Vielzahl von Ebenen des Objekts (10) abzutasten, wobei sich mindestens zwei der Ebenen schneiden.

9. Verfahren nach Anspruch 1, wobei die Röntgen-Abtasteinrichtung einen Plattendetektor umfasst.

10. Vorrichtung (44) zur Messung eines Objekts (10), wobei die Vorrichtung Folgendes umfasst:

ein Registrierungsmodul (48), das dazu konfiguriert ist, das Objekt mit einem nominalen Modell des Objekts zu registrieren, das insbesondere ein 3D-CAD-Modell umfasst, wobei das Objekt eine Vielzahl von Merkmalen (38, 40) aufweist, um automatisch zu bestimmen, wo mindestens ein Merkmal des Objekts innerhalb des abzutastenden Objekts liegt, und eine effiziente Bewegungsbahn für eine Röntgen-Abtasteinrichtung zu berechnen, um das mindestens eine Merkmal des Objekts abzutasten, wobei es sich bei dem Berechnen um eine Funktion des Registrierens des Objekts und des Modells handelt;

eine Haltevorrichtung (28), die dazu konfiguriert ist, das Objekt zu tragen;

eine Steuerung (54), die mit dem Registrierungsmodul wirkverbunden ist, wobei die Steuerung dazu konfiguriert ist, die Röntgen-Abtasteinrichtung zu steuern, um, durch Bewegen oder Umkreisen eines Quellen-/Detektor-Paares (22, 26) um das Objekt entlang eines Bogens (θ), weniger als das gesamte Objekt entlang der effizienten Bewegungsbahn abzutasten, um visuelle Daten zu erzeugen, die mindestens einen abgetasteten Abschnitt darstellen, wobei der mindestens eine abgetastete Abschnitt mindestens ein Merkmal beinhaltet;

ein Rekonstruktionsmodul (50), das mit der Steuerung wirkverbunden ist, wobei das Rekonstruktionsmodul dazu konfiguriert ist, den mindestens einen abgetasteten Abschnitt des re-

gistrierten Objekts anhand der visuellen Daten volumetrisch zu rekonstruieren, um eine volumetrische Rekonstruktion zu erzeugen; und ein Messmodul (52), das mit dem Rekonstruktionsmodul wirkverbunden ist, wobei das Messmodul dazu konfiguriert ist, das mindestens ein Merkmal anhand der volumetrischen Rekonstruktion zu messen, das insbesondere ein Gehäuse (21) umfasst, das eine Kammer bildet, die die Haltevorrichtung und die Röntgen-Abtastvorrichtung enthält.

11. Vorrichtung (44) nach Anspruch 10, wobei die Haltevorrichtung (28) sowohl in einer Translationsrichtung als auch in einer Drehrichtung beweglich ist.
12. Computerprogrammprodukt zur Verwendung an einem Computersystem (20) zur Messung eines Objekts (10), wobei das Computerprogrammprodukt ein materielles, nichttransientes vom Computer verwendbares Medium umfasst, auf dem sich vom Computer lesbarer Programmcode befindet, wobei der vom Computer lesbare Programmcode Folgendes umfasst:

Programmcodem zum Registrieren des Objekts mit einem nominalen Modell des Objekts, das insbesondere ein 3D-CAD-Modell umfasst, wobei das Objekt eine Vielzahl von Merkmalen (38, 40) aufweist;

Programmcodem zum Bestimmen von mindestens einem Merkmal des abzutastenden Objekts;

Programmcodem zum Berechnen einer effizienten Bewegungsbahn für eine Röntgen-Abtasteinrichtung, um das mindestens ein Merkmal des Objekts abzutasten, wobei es sich bei dem Berechnen um eine Funktion des Registrierens des Objekts mit dem Modell handelt;

Programmcodem zum Steuern der Röntgen-Abtasteinrichtung zum Abtasten (506), durch Bewegen oder Umkreisen eines Quellen-/Detektor-Paares (22, 26) um das Objekt entlang eines Bogens (θ), von weniger als dem gesamten Objekt entlang der effizienten Bewegungsbahn, um visuelle Daten zu erzeugen, die mindestens einen abgetasteten Abschnitt darstellen, wobei der mindestens eine abgetastete Abschnitt mindestens einen Abschnitt des mindestens einen, insbesondere eines inneren und/oder äußeren Merkmals beinhaltet;

Programmcodem zum volumetrischen Rekonstruieren (508) des mindestens einen abgetasteten Abschnitts des registrierten Objekts anhand der visuellen Daten, wobei das Rekonstruieren zu einer volumetrischen Rekonstruktion führt; und

Programmcodem zum Messen (510) des mindes-

tens einen Merkmals anhand der volumetrischen Rekonstruktion.

13. Computerprogrammprodukt nach Anspruch 12, wobei der Programmcode zum Bestimmen Programmcode zum Bestimmen einer Vielzahl von Merkmalen (38, 40) des abzutastenden Objekts (10) umfasst, wobei der Programmcode zum Steuern Programmcode zum Steuern der Röntgen-Abtasteinrichtung umfasst, um weniger als die Gesamtheit des Objekts abzutasten (506), um visuelle Daten zu erzeugen, die mindestens einen abgetasteten Abschnitt darstellen, wobei der mindestens eine abgetastete Abschnitt die Vielzahl von Merkmalen beinhaltet.
14. Computerprogrammprodukt nach Anspruch 12, wobei Programmcode zum Steuern Programmcode zum Steuern der Röntgen-Abtasteinrichtung umfasst, um visuelle Kennzeichen zu erzeugen, die eine Vielzahl von abgetasteten Abschnitten darstellen.
15. Computerprogrammprodukt nach Anspruch 12, ferner umfassend Programmcode zum Laden (500) des Modells des Objekts in eine CT-Maschine (18), die die Röntgen-Abtasteinrichtung umfasst.

Revendications

1. Procédé de mesure d'un objet (10), le procédé comprenant :

le calage de l'objet avec un modèle nominal, comprenant en particulier un modèle CAD 3D, de l'objet, l'objet ayant une pluralité de particularités ;

la détermination d'au moins une particularité (38, 40) de l'objet à balayer ;

le calcul d'une trajectoire efficace pour qu'un dispositif de balayage à rayons X balaie l'au moins une particularité de l'objet, le calcul étant fonction du calage de l'objet avec le modèle ;

la commande du dispositif de balayage à rayons X pour balayer (506) en déplaçant ou en satellisant une paire source/détecteur (22, 26) autour de l'objet le long d'un arc (θ), inférieur à l'objet entier le long de la trajectoire efficace pour produire des données visuelles représentant au moins une portion balayée, l'au moins une portion balayée comportant au moins une portion de l'au moins une particularité ;

la reconstruction volumétrique (508) de l'au moins une portion balayée de l'objet calé à partir des données visuelles, la reconstruction produisant une reconstruction volumétrique ; et

la mesure (510) de l'au moins une particularité à partir de la reconstruction volumétrique, comprenant en particulier le chargement (502)

de l'objet dans une machine CT (18) comprenant le dispositif de balayage à rayons X.

2. Procédé selon la revendication 1, dans lequel la détermination comprend la détermination d'une pluralité de particularités (38, 40) de l'objet (10) à balayer, la commande comprenant la commande du dispositif de balayage à rayons X pour balayer moins de la totalité de l'objet pour produire des données visuelles représentant au moins une portion balayée, l'au moins une portion balayée comportant la pluralité de particularités. 5
3. Procédé selon la revendication 2, dans lequel la commande comprend la commande du dispositif de balayage à rayons X pour produire des signes distinctifs visuels représentant une pluralité de portions balayées. 10
4. Procédé selon la revendication 1, dans lequel la particularité comporte une particularité interne de l'objet (10). 15
5. Procédé selon la revendication 1, dans lequel la particularité comporte une particularité externe de l'objet (10). 20
6. Procédé selon la revendication 1, dans lequel le dispositif de balayage à rayons X comprend une source (22) qui se déplace de moins de 360 degrés autour de l'objet (10) lors du balayage de l'objet. 25
7. Procédé selon la revendication 1, dans lequel l'objet (10) est positionné sur un bâti (28) qui n'obstrue pas le dispositif de balayage à rayons X, en particulier dans lequel le bâti est mobile à la fois dans une direction de translation et dans une direction de rotation. 30
8. Procédé selon la revendication 1, dans lequel la commande comprend la commande d'un dispositif de balayage à rayons X pour balayer une pluralité de plans de l'objet (10), au moins deux des plans étant en intersection. 35
9. Procédé selon la revendication 1, dans lequel le dispositif de balayage à rayons X comprend un détecteur de panneau plat. 40
10. Appareil (44) de mesure d'un objet (10), l'appareil comprenant : 45
 - un module de calage (48) configuré pour caler l'objet avec un modèle nominal de l'objet, comprenant en particulier un modèle CAD 3D, l'objet ayant une pluralité de particularités (38, 40), pour déterminer automatiquement où se trouve au moins une particularité de l'objet au sein de 50

l'objet à balayer, et pour calculer une trajectoire efficace pour qu'un dispositif de balayage à rayons X balaie l'au moins une particularité de l'objet, le calcul étant fonction du calage de l'objet et du modèle ;

un bâti (28) configuré pour supporter l'objet ;
 un dispositif de commande (54) couplé opérationnellement au module de calage, le dispositif de commande étant configuré pour commander le dispositif de balayage à rayons X pour balayer, en déplaçant ou en satellisant une paire source/détecteur (22, 26) autour de l'objet le long d'un arc (θ), inférieur à l'objet entier le long de la trajectoire efficace pour produire des données visuelles représentant au moins une portion balayée, l'au moins une portion balayée comportant au moins une particularité ;
 un module de reconstruction (50) couplé opérationnellement au dispositif de commande, le module de reconstruction étant configuré pour reconstruire de façon volumétrique l'au moins une portion balayée de l'objet calé à partir des données visuelles pour produire une reconstruction volumétrique ; et
 un module de mesure (52) couplé opérationnellement au module de reconstruction, le module de mesure étant configuré pour mesurer l'au moins une particularité à partir de la reconstruction volumétrique,
 comprenant en particulier un boîtier (21) formant une chambre contenant le bâti et le dispositif de balayage à rayons X.

11. Appareil (44) selon la revendication 10, dans lequel le bâti (28) est mobile à la fois dans une direction de translation et dans une direction de rotation.

12. Produit-programme d'ordinateur à utiliser sur un système d'ordinateur (20) pour mesurer un objet (10), le produit-programme d'ordinateur comprenant un support utilisable par ordinateur, non transitoire tangible sur lequel est stocké un code de programme lisible par ordinateur, le code de programme lisible par ordinateur comprenant : 55

un code de programme pour le calage de l'objet avec un modèle nominal de l'objet, comprenant en particulier un modèle CAD 3D, l'objet ayant une pluralité de particularités (38, 40) ;
 un code de programme pour la détermination d'au moins une particularité de l'objet à balayer ;
 un code de programme pour le calcul d'une trajectoire efficace pour qu'un dispositif de balayage à rayons X balaie l'au moins une particularité de l'objet, le calcul étant fonction du calage de l'objet avec le modèle ;
 un code de programme pour la commande du dispositif de balayage à rayons X pour balayer

(506), par déplacement ou satellisation d'une
 paire source/détecteur (22, 26) autour de l'objet
 le long d'un arc (θ), inférieur à l'objet entier le
 long de la trajectoire efficace pour produire des
 données visuelles représentant au moins une 5
 portion balayée, l'au moins une portion balayée
 comportant au moins une portion de l'au moins
 une particularité, en particulier une particularité
 interne et/ou externe ;
 un code de programme pour la reconstruction 10
 volumétrique (508) de l'au moins une portion ba-
 layée de l'objet calé à partir des données visuel-
 les, la reconstruction produisant une recons-
 truction volumétrique ; et
 un code de programme pour la mesure (510) de 15
 l'au moins une particularité à partir de la recons-
 truction volumétrique.

13. Produit-programme d'ordinateur selon la revendica-
 tion 12, dans lequel le code de programme pour la 20
 détermination comprend un code de programme
 pour la détermination d'une pluralité de particularités
 (38, 40) de l'objet (10) à balayer, le code de program-
 me pour la commande comprenant un code de pro-
 gramme pour la commande du dispositif de balayage 25
 à rayons X pour balayer (506) moins de la totalité de
 l'objet pour produire des données visuelles repré-
 sentant au moins une portion balayée, l'au moins
 une portion balayée comportant la pluralité de par-
 ticularités. 30
14. Produit-programme d'ordinateur selon la revendica-
 tion 12, dans lequel le code de programme pour la
 commande comprend un code de programme pour
 la commande du dispositif de balayage à rayons X 35
 pour produire des signes distinctifs visuels représen-
 tant une pluralité de portions balayées.
15. Produit-programme d'ordinateur selon la revendica-
 tion 12, comprenant en outre un code de programme 40
 pour le chargement (500) du modèle de l'objet dans
 une machine CT (18) comprenant le dispositif de ba-
 layage à rayons X.

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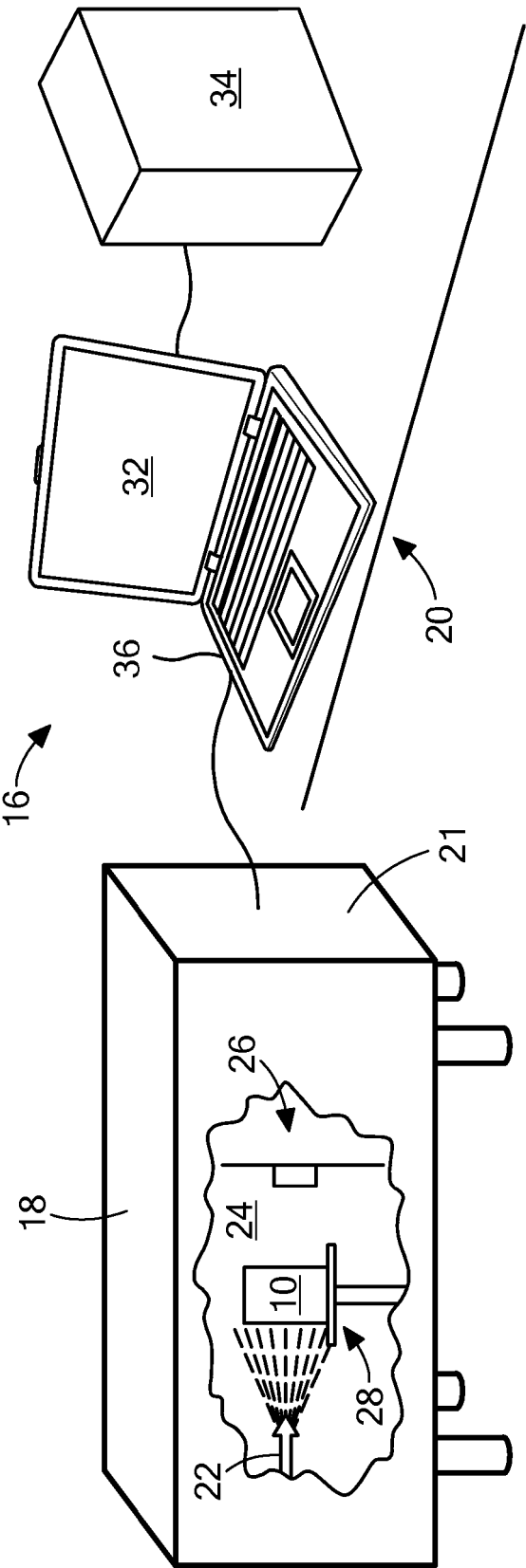


FIG. 1

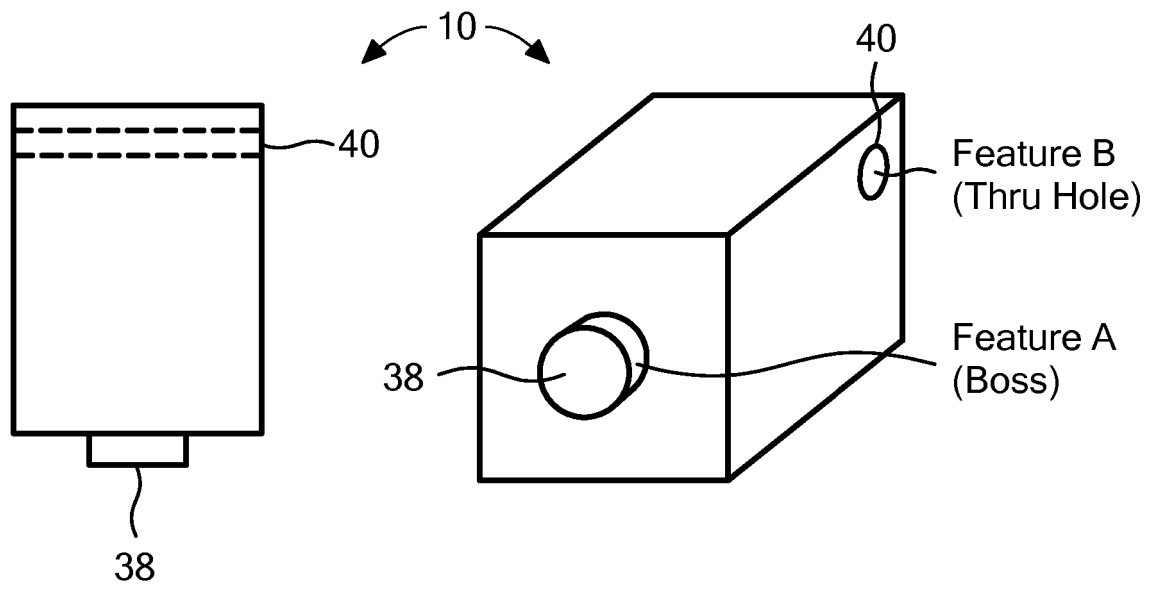


FIG. 2A

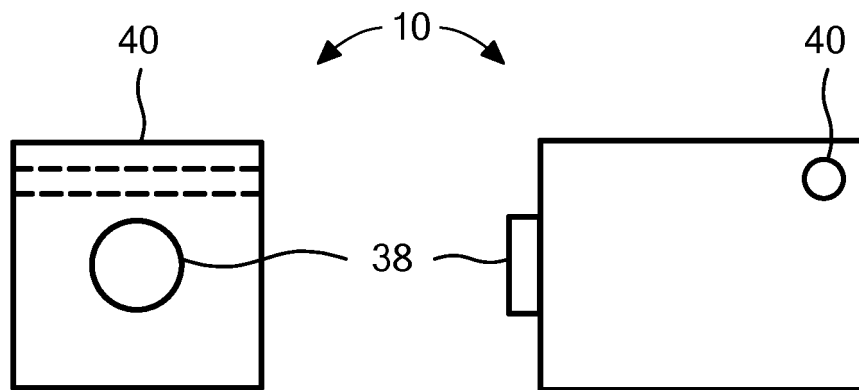


FIG. 2B

Scan Orientation For Feature A :

$$\phi = 0^\circ$$

$\theta = 0^\circ - 360^\circ$ for N projections about major scan axis

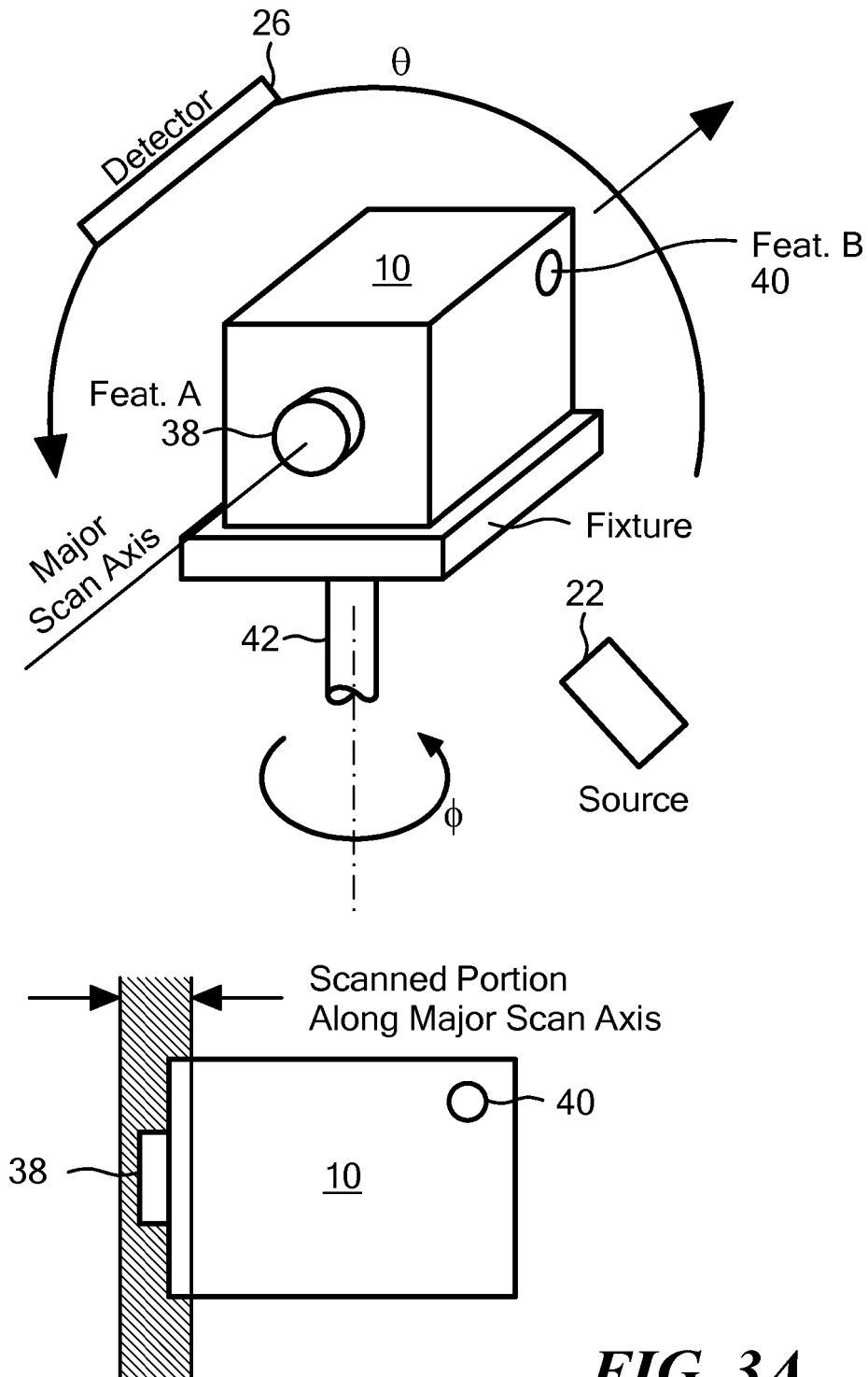


FIG. 3A

Scan Orientation For Feature B :

$$\phi = 90^\circ$$

$\theta = 0^\circ - 360^\circ$ for N projections about major scan axis

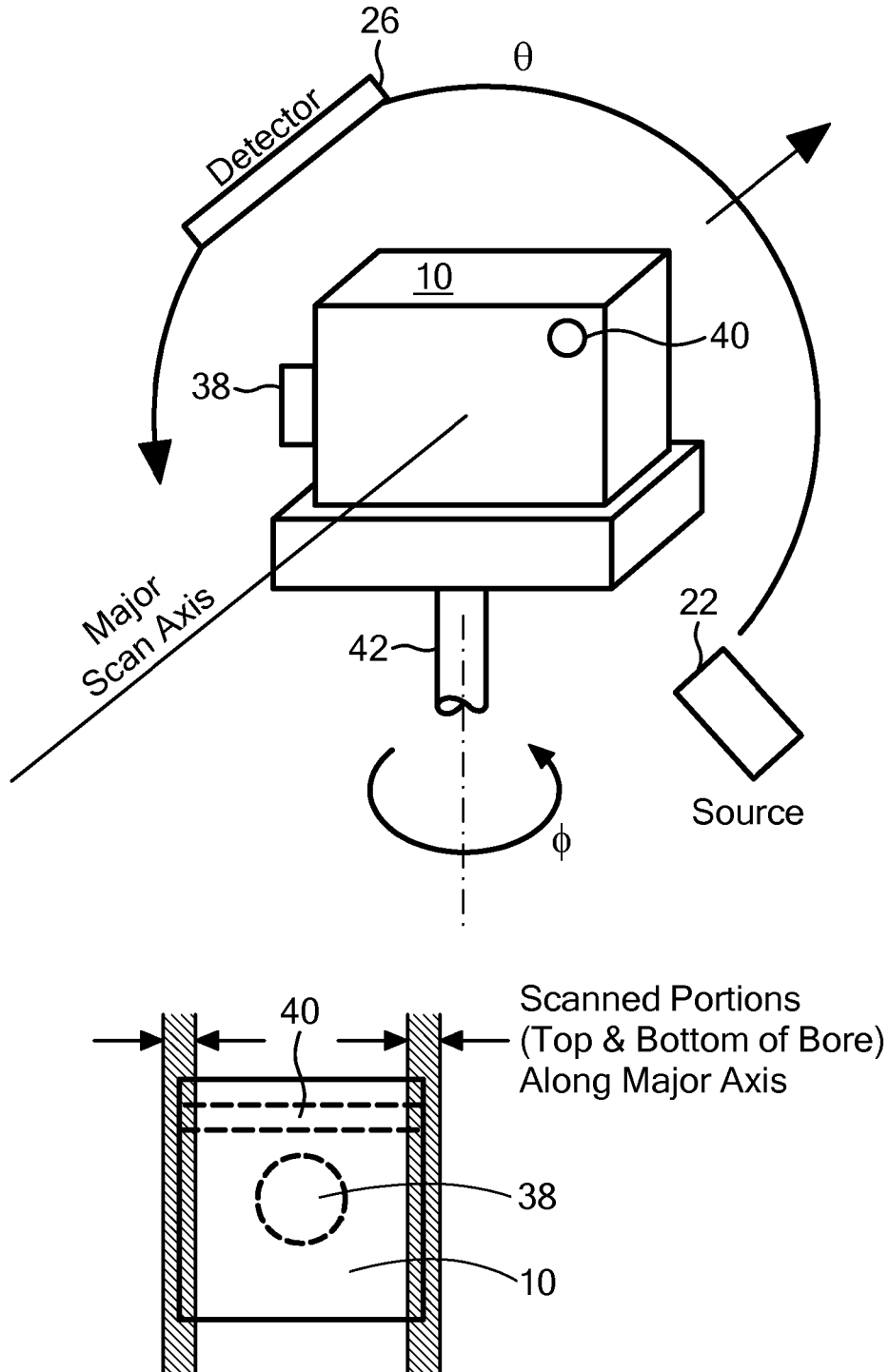


FIG. 3B

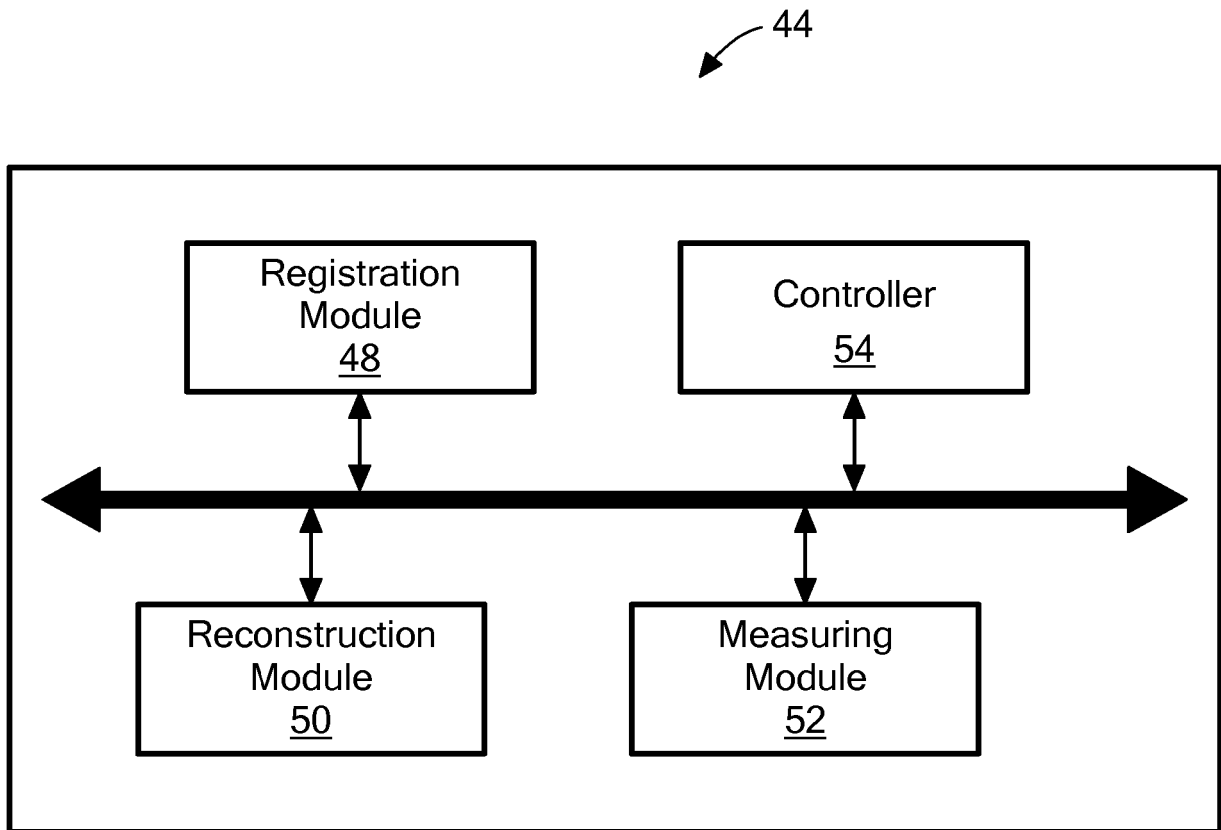
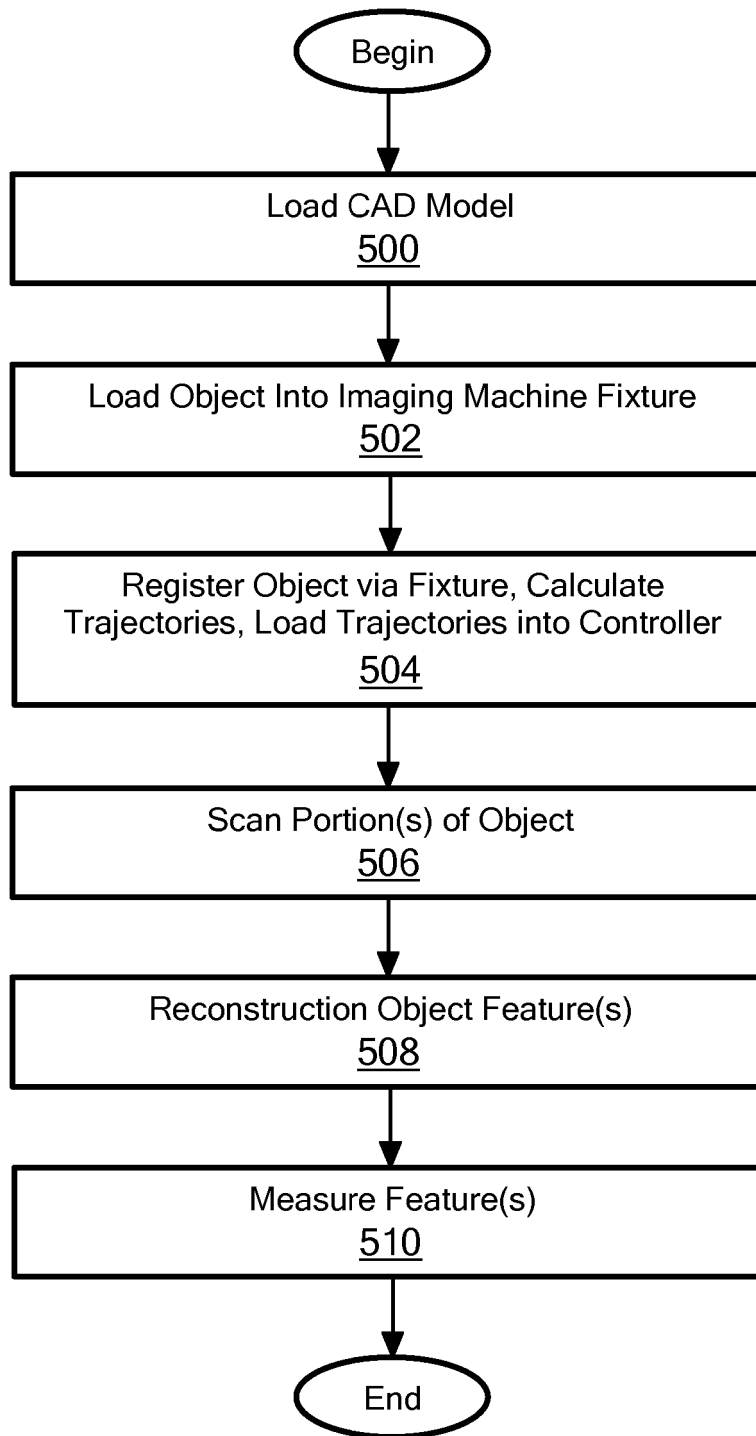


FIG. 4

***FIG. 5***

REFERENCES CITED IN THE DESCRIPTION

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